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Global Biomass Variation and Its Geodynamic Effects: 1982–98

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ABSTRACT: Redistribution of mass near Earth's surface alters its rotation, gravity field, and geocenter location. Advanced techniques for measuring these geodetic variations now exist, but the ability to attribute the observed modes to individual Earth system processes has been hampered by a shortage of reliable global data on such processes, especially hydrospheric processes. To address one aspect of this deficiency, 17 yr of monthly, global maps of vegetation biomass were produced by applying field-based relationships to satellite-derived vegetation type and leaf area index. The seasonal variability of biomass was estimated to be as large as 5 kg m^{-2} . Of this amount, approximately 4 kg m^{-2} is due to vegetation water storage variations. The time series of maps was used to compute geodetic anomalies, which were then compared with existing geodetic observations as well as the estimated measurement sensitivity of the Gravity Recovery and Climate Experiment (GRACE). For gravity, the seasonal amplitude of biomass variations may be just within GRACE's limits of detectability, but it is still an order of magnitude smaller than current observation uncertainty using the satellite-laser-ranging technique. The contribution of total biomass variations to seasonal polar motion amplitude is detectable in today's measurement, but it is obscured by contributions from various other sources, some of which are two orders of magnitude larger. The influence on the length of day is below current limits of detectability. Although the nonseasonal geodynamic signals show clear interannual variability, they are too small to be detected.

KEYWORDS: Biogeochemical cycles, Earth rotation variations, Time-variable gravity, Remote sensing

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1. Introduction

A great quantity of mass, on the order of 1 teraton (10^{15} kg; equivalent to 1000 km³ of water), is sequestered in the body of living organisms as biomass. The majority of global biomass exists as vegetation, which covers much of the land surface. Vegetation density is highly variable geographically, but it also varies in time. It undergoes large seasonal variations, including the emergence and shedding/drying of leaves of deciduous trees in the vast temperate zones, the crop cycles in agricultural land, and the seasonal growth and disappearance of opportunistic plants in the Arctic. It also undergoes interannual variations dependent upon land use and climate variability.

Temporal variations of biomass distribution were computed and are presented below for 17 yr from which consistent satellite observations of vegetation properties are available. The resultant global geodynamic effects were quantified and compared against geodetic observations, for both seasonal and interannual signals. In accounting for the destination of the water involved it was assumed that plants exchange water from their land location ultimately with the (uniform) ocean as source and sink. There are also biomass variations in the ocean itself, but the mass is floating and thus inseparable from ocean water mass, so these were not considered here.

The geodynamic effects of mass transport in the Earth system include variations in Earth's rotation (e.g., Gross 2000), gravity field (e.g., Nerem et al. 1993), and geocenter (e.g., Chao et al. 2000; see Table 1). Although relatively tiny, these variations have been observed using highly precise modern space geodetic techniques (Smith and Turcotte 1993). What is observed is the total effect of redistributions of all forms of mass, including those that occur near Earth's surface in the atmosphere, hydrosphere, and cryosphere (e.g., Kuehne and Wilson 1991). These mass variations predominate on daily to interannual time scales, superimposed upon those in the solid Earth, which are generally greater in magnitude but far longer in time scale.

5. Summary

Global maps of vegetation biomass were produced for each month from January 1982 to December 1998 by applying field-based relationships to AVHRR measurements of LAI and vegetation type. These maps were used to compute geodetic anomalies, which in turn were compared with existing data on Earth's rotation variations, geocenter motion, and time-variable gravity, including the current accuracy of GRACE-derived terrestrial mass changes. It was determined that the seasonal amplitude of biomass far exceeds the interannual variability, reaching 5 kg m⁻² in certain regions. The interannual signatures of ENSO and the 1991 eruption of Mount Pinatubo are nevertheless recognizable in the biomass-induced geodynamic signals. The seasonal geodetic anomalies are still one to two orders of magnitude smaller than those resulting from atmospheric and other terrestrial hydrological processes. The biomass variability is at or above GRACE's limits of detectability globally for harmonic degrees 4–14 and possibly, with expected future improvements in the retrieval algorithms, over certain regions including parts of temperate North America and Eurasia. Compared with other modern precise space geodetic measurements, the seasonal amplitudes are marginally detectable or one order of magnitude too small to be detected or identified. The biomass contributions, especially in the cases where they are detectable albeit marginally, should be considered and modeled in order to achieve a complete understanding and interpretation of the observational data.